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NETWORK EFFECTS AND TOTAL ECONOMIC IMPACT IN TRANSPORT APPRAISAL

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ABSTRACT

It is claimed that transport infrastructure projects have network effects which are not taken into account in the appraisal of these projects. This paper reviews the concept of network effects, relates this to transport appraisal practice, and links to the concept of 'total economic impact'. The limitations of transport modelling and appraisal in estimating total economic impact are reviewed. Good quality appraisals should be capable of picking up relevant network effects in the transport market, but the state of the art remains limited on the linkages between transport and the wider economy.

Keywords: Network effects, total economic impact, infrastructure assessment

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1 INTRODUCTION

European policymakers have been interested for some years now in network effects - see, for example Turró (1999), van Exel *et al* (2002), and Pearman *et al* (2003). There is a widely-held belief among policymakers that transport infrastructure projects give rise to network effects which are not taken into account in the appraisal of these projects. Such effects could be an important source of benefits from the implementation of the European Commission's transport sector policy as set out in '*European Transport Policy for 2010: Time to Decide*' (EC, 2001).

Many of the initiatives specified in '*Time to Decide*' are about developing the 'network' aspects of the TEN-T (Trans-European Transport Networks). For example, the rail networks of Spain and Portugal currently operate on a different gauge of track from the rest of Europe. One of the initiatives at the European level is to bring about a harmonisation of track gauge, so creating an interoperable international network. Another set of initiatives relates to border crossings. The High Level Group report on the TEN-T (2003) identified and gave top priority to at least 15 infrastructure projects which will improve border crossings between countries in the EU15 and the new member states. Other 'network' initiatives in Europe include the GALILEO satellite navigation project, which will also facilitate electronic charging using a common technology across the European road network, and the creation of a multi-modal logistics centre in Poland linking to the Russian rail network (also on a different gauge). '*Time to Decide*' also outlines one completely new network – the so-called ‘motorways of the sea’.

There is no doubt that, when implemented, these initiatives will change the physical network, and the pattern of use made of it. But the question is – what exactly are network effects? Are they simply the economist’s user benefits translated into politicians’ language? Or are they something more than that? How are they potentially and actually captured in models of the transport and economic system? What is the state of the art and how significant are network effects in transport? This is the agenda for this paper.

2 NETWORK EFFECTS FROM AN ECONOMIC PERSPECTIVE

Transport infrastructure has a physical presence in the form of roads, inland waterways, airports and so on. However, *transport networks* are not always defined by the existence of physical infrastructure: ships and aircraft use a set of routes largely without physical markings. Conceptually, a transport network is simply an interconnected set of links and nodes. The European transport network is not, however, a single homogenous entity. It is a combination of modal networks within which there are hierarchies such as national, regional and local roads. Management of this large and complex network is devolved so that there can be conflicts between local and global optimisation within modes, between modes and between countries. As others have shown, there can be uncounted, uncosted effects in related markets (Roy,1995;Van Exel et al.,2002).

Consider as a starting point an old-style single mode, fixed matrix appraisal of a transport scheme in a tightly drawn study area with all traffic growth created by exogenous changes in income and fuel prices. For example, this was the technology of appraisal exemplified by the COBA Manual in the UK in the 1980s. It gives a measure of scheme benefits under a restrictive set of conditions and represents our reference case.

Relative to this form of appraisal, it is possible to identify three sorts of interactions which should ideally be taken into account. Firstly, there are interactions with the rest of the transport system. There may, for example, be behavioural response, such as changes in destination, invalidating the fixed matrix assumption. There may be effects outside the study area, or on other modes. The effects may spill across national boundaries. A more fully specified transport model would be capable in principle of capturing these effects.

Secondly, there are interactions between transport and the environment. These impacts are not discussed further here, not because they are unimportant, but because their status as technological externalities is well understood.

Thirdly, there are interactions between transport and the economy. Transport changes bring about accessibility changes which in turn stimulate land development, and ultimately changes in the pattern of outputs, prices and wages. Transport is an intermediate good so the linkages back to the labour and land markets and forward to the goods and services markets are highly relevant to transport pricing and investment policies.

Transport is not unique; there are many interactions in the economic system. Every time a new good is created, demand is abstracted from competing goods. Under conditions of constant returns to scale – that is, under competitive conditions – there are no second round consequences for economic welfare. Demand falls, output adjusts and prices for substitutes and costs remain unchanged.

Suppose, however, that markets are not subject to constant returns. Then changes in transport demand will have consequences for unit costs and/or prices in transport and related markets. We define network effects as the second round reverberations on costs and prices in related markets as a result of a transport improvement. These may be:

- Effects in other parts of the transport system, which we label *transport network effects*

- Effects in the economic sectors which transport connects by forward and backward linkages – *transport/economy network effects*.

Transport is of course far from the only sector to which this sort of argument applies. Others include telecommunication networks, broadcasting and the internet, and networks to supply electricity, gas and water (see Shy, 2001 for an overview). All these network goods have one or more of the following characteristics:-

(i) *Sunk costs and economies of scope/density on the supply side*, and specifically so-called sub-additivity in production (e.g. Baumol, Panzar and Willig, 1982; Jara-Diaz, 2000).

(ii) *Congestibility* (see e.g. Mayer and Sinai, 2003). The effects of constrained capacity and growing demand are widespread in network industries.

(iii) *Positive consumption externalities* whereby an individual's valuation of a good (e.g. phone service) is dependent in part on the number of other users attached to the network (see Liebowitz and Margolis, 1998). This characteristic is directly relevant for so-called 'two-way' networks such as transport, telecommunications and the internet, where the purpose of the connection is largely to interact with people or businesses at the other end of the connection. For 'one-way' networks such as gas or electricity supply, the consumer is concerned only with their own consumption of the network good, and will experience consumption externalities only indirectly if increasing numbers of other consumers leads the network provider to increase the varieties or spatial availability of service on offer.

These characteristics are what cause the second round effects on costs and prices which may reinforce or dampen the primary effect of the investment project.

On the supply side - sunk costs and economies of scale/ scope/density

The properties of certain types of transport infrastructure and services imply that capacity-enhancing investment will result in a reduction of unit costs (a network effect). Classic examples include railway infrastructure and airline operations. A train lengthening programme which caters for a doubling of demand between two points does not require a doubling of all inputs, due to economies of density of the rail network. Hub and spoke operations, and the use of as large a vehicle as possible, are also classic devices for achieving economies of density and scale, whether in airlines, railways or bus networks. Again, infrastructure improvements may enable transport operators to increase the number of routes offered or destinations served. Economies of scope imply that the average costs per trip fall as the number of products (routes) offered increases. So, investment in a complementary part of the network will feed additional traffic lowering unit costs; conversely investment in a competing network will abstract traffic, reducing density and raising unit costs.

There is substantial quantitative evidence that economies of scale, scope and density exist within transport networks, particularly rail and air networks (see e.g. Winston, 1985; Jara-Díaz, 1988; Pels and Rietveld, 2000; Jara-Díaz and Basso, 2003). Of course it is not just the transport market that is subject to such economies. The New Economic Geography literature (Krugman, 1991) emphasises that interactions between the transport network and the wider economy allow businesses to rationalise and exploit economies of scale thereby lowering unit costs. Such a change can be driven by a change in transport supply. We therefore see that economies of scale, scope and density in transport using sectors of the wider economy (e.g. manufacturing) are also a source of network effects.

Supply-demand interaction - congestibility

A classic example of supply-demand interaction is traffic congestion. Congestion on one transport route or mode affects journey times, costs and demand for other routes or modes. This is because demand is displaced from the congested routes onto those that are less congested. An investment that alleviates congestion on one route will therefore affect the demands and costs of using alternative options. Traffic congestion and the potential for infrastructure or services to become congested or overcrowded are therefore sources of transport network effects.

On the demand side – positive consumption externalities

Transport is a derived demand. That is the demand to travel stems from the demand to engage in a certain activity: attend work, meet friends, meet to conduct business, buy products, sell products, and so on. Transport is therefore all about connecting people and production/consumption systems in some form of economic linkage. We contend that changes in the potential number of economic linkages that can be formed (e.g. through a transport infrastructure investment) will lead to positive consumption externalities and these are a source of network effect.

As a transport network is expanded or is improved more linkage opportunities become available at a given price (generalised cost). This can be seen in Figure 1 in the linkage opportunities offered by an airline as it increases the number of its routes from one to 20, operated out of a single hub airport. As the number of routes increases by one (from n to $n+1$), the number of opportunities for individuals or firms to link together increases by $n+1$.

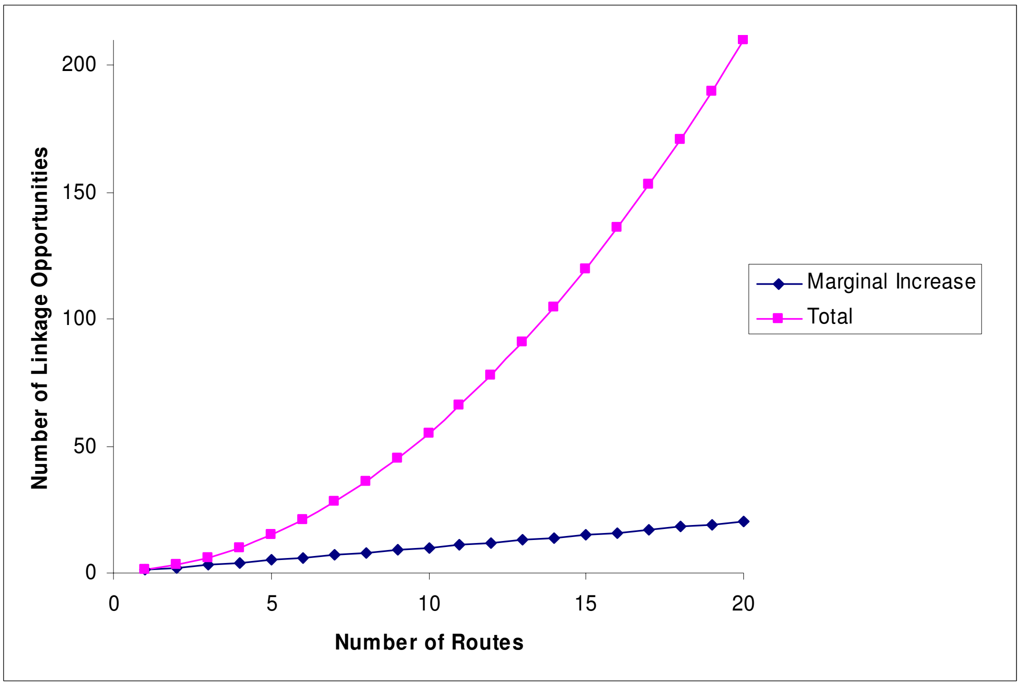

FIGURE 1: INCREASING LINKAGE OPPORTUNITIES WITH NETWORK EXPANSION IN A HUB AND SPOKE NETWORK

In a more dramatic case, if two unconnected networks are connected by a 'missing link' across a geographical or political boundary, there could be a sudden large increase in the number of linkage opportunities that become available. For example, before 'Network D' (with D destinations) and 'Network E' (with E destinations) are connected the total number of linkage opportunities is only:

$$\sum_{n=1}^{D}(n-1) \text{ plus } \sum_{n=1}^{E}(n-1).$$

By connecting the two networks the number of opportunities increases to:

$$\sum_{n=1}^{D+E}(n-1)\,.$$

The potential power of this argument is obvious: if a trading block of 20 cities of over 1 million people is combined with another trading block of 10 cities, the number of opportunities to form economic linkages increases by 80 per cent. There are of course questions about what proportion of output is actually traded that is capable of overcoming the transport cost barrier. However, where the historical barrier has been artificial (e.g. political) rather than economic, one would expect improved transport infrastructure to act as a stimulus to integration of product and factor markets.

Setting this characteristic of linkage opportunities into an economic context: from the perspective of the individual or firm, the more opportunities that exist the better. Drawing on analyses developed within the context of telephone networks the utility of each individual consumer increases with the number of other consumers connected to the network. Within a transport context this can be expressed as an indirect utility function where instead of consumers we are interested in linkage opportunities to meet people or to produce/consume:

$U = U(j, -GC)$

where j is the vector of destinations (linkages) accessible at the vector of prices (generalised costs) GC.

As utility is related to the number of opportunities for linkages to be made, if there is an exponential increase in those opportunities, as occurs with a network expansion (as in the hub and spoke example and the two trading block example), then there can be a significant increase in utility. Benefits of network expansion occur not only to those individuals newly connected to the network, but also to the large number of individuals who are already connected, since their opportunities for travel and trade will also expand. Such incidental (external) benefits are termed ‘consumption externalities’. Consumption externalities give rise to thicker labour markets, better producer-supplier linkages and knowledge spillovers – which are all forms of agglomeration economies.

3 CAPTURING NETWORK EFFECTS IN TRANSPORT-ECONOMY MODELS

3.1 From transport initiative to network effect

We have already set out the economic stimuli that generate network effects: economies of scale, scope and density and congestion on the supply side and consumption externalities - the opportunities to change or create additional economic linkages - on the demand side. Such stimuli need to be reflected in the modelling system if the scale and sign of network effects are to be forecast robustly.

At first glance, these stimuli do not appear to relate particularly well to existing methods used to model transport project impacts, particularly on the demand side. For example what do gravity models, logit models and Wardrop's Users' Equilibrium have in common with 'consumption externalities' and 'economic linkages'? In fact, such modelling approaches are conceptually consistent with the economic specification of network effects. This is because it is the utility maximising behaviour of individuals and the profit maximising behaviour of firms that link the economic causes of network effects to their manifestation on transport networks and within the economy. Utility and profit maximising behaviour also underpin the vast majority of transport and economy models, as most models include some form of function that minimises generalised cost. Figure 2 shows the transport and economy system, and the dynamic nature of the interactions within it. The key issue for modelling is the capability in practice of representing this transport/economy system.

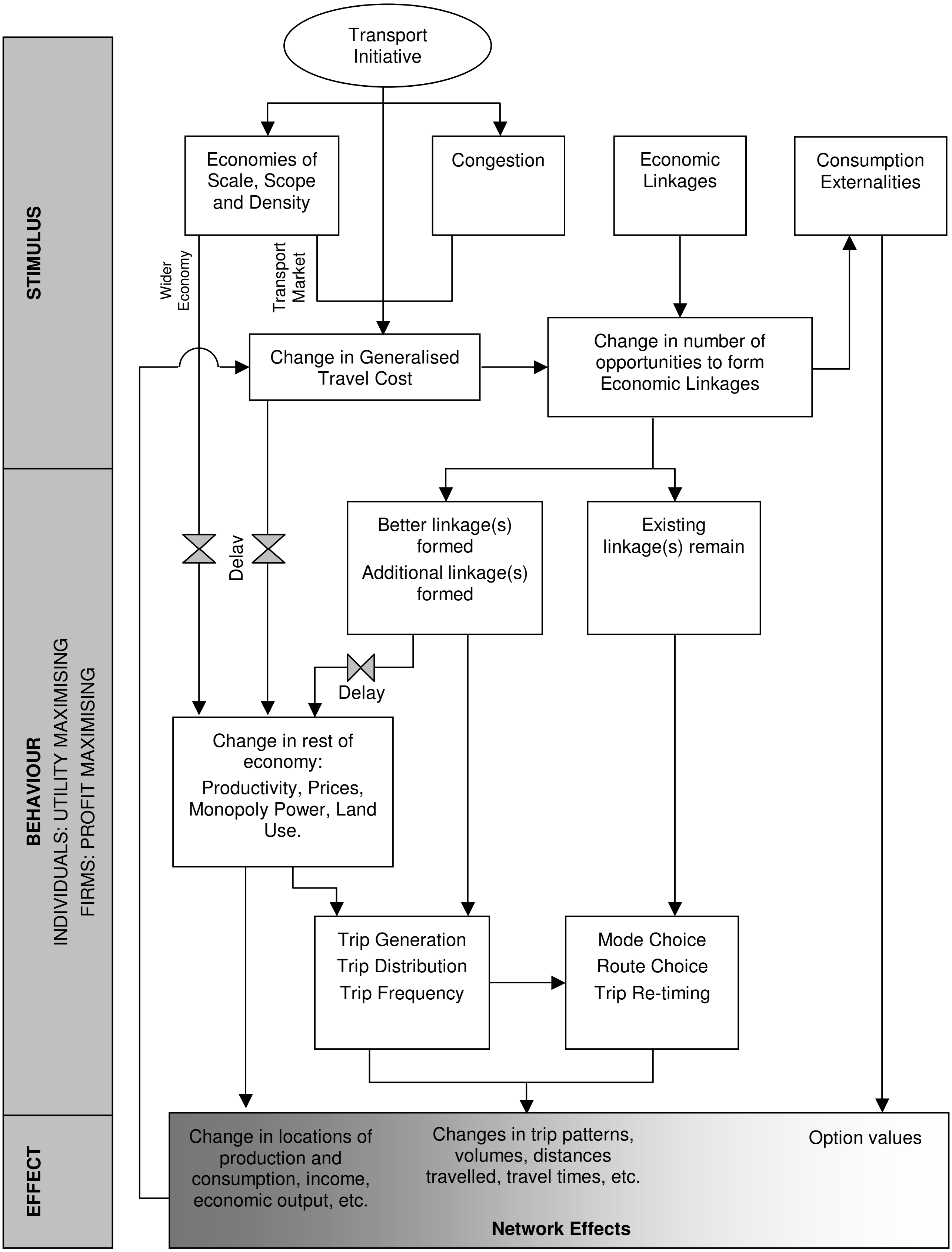

FIGURE 2: FROM TRANSPORT INTIATIVE TO NETWORK EFFECT

3.2 Modelling and appraisal in practice

In principle tools exist to model all aspects of the transport-economy system. Transport behaviour models are well developed as are models of transport supply. Tools are now also available to model the interaction between land use and transport as well as linkages between the transport and the economic system - including both spatial computable general equilibrium models (SCGE) and transport macro-economic models. In practice, however, these tools are often applied in isolation or are only simply linked.

Transport behaviour models are almost always used for project appraisal. However, often these are only coarsely linked to a public transport supply model if at all - even for sophisticated appraisals such as the UK multi-modal studies (Bates *et al*, 2004) – and only rarely are they linked to either a land-use model or an economic model. When transport and economic models are linked it may often be in a simple manner that allows the models to converge but at the cost of preventing changes in the wider economy to be fed back into the transport market. This is the case for the link between the SCENES transport model and the CGEurope SCGE model (Bröcker *et al*, 2001) as used in the IASON project[2].

[2] IASON was an EC 5th framework research project with the objective of improving the understanding of the impact of transportation policies on short- and long-term spatial development in the EU.

Furthermore for technical, administrative and budgetary reasons the modelling and therefore the appraisal may be coarser than desired. Transport behaviour models with a large geographic scope may have only a weak representation of congestion due to a mixture of data availability issues or model run times. For example, the large zone sizes of the EU-wide transport models SCENES, NEAC and VACLAV, reviewed as part of the IASON project, mean that short distance trips (intra-zonal trips) are excluded, thereby limiting the models' abilities to replicate congestion effects (Laird *et al*, 2003). Networks may also be incomplete, so that there are effects outside the studied modes, areas and networks. This may arise for reasons of data acquisition costs, model complexity and computing power. In such situations the study area is cut down, the modelling system is simplified and elasticities are used to cover behavioural responses that are excluded from the analysis and to represent the generative effects of new infrastructure. Such elasticities may be rough and ready values or may even be set to zero. It is these practical restrictions which render the transport model incomplete and raise questions about how fully transport network effects are being picked up by the transport model. These questions become acute if networks are artificially truncated at regional or national boundaries.

Moving to the transport-economy linkages, SCGE models are also in the infancy of their development and simplifications in the representation of labour markets, labour migration, household behaviour, the product market, the land market and the level of industrial disaggregation have to be made. CGEurope for example has only a weak representation of the labour market and the treatment of non-working time but a good representation of monopolistic competition and of economies of scale in the product market (Schade *et al*, 2004).

From the economic evaluation perspective there are additional technical difficulties associated with placing an economic value on certain transport characteristics (e.g. reliability, congestion, overcrowding).

Obviously, the further the modelling system falls short of ideal, the greater the potential for effects which are unmeasured within the appraisal (both positive and negative). It is therefore critical to the robustness of any appraisal that the most appropriate modelling tools are used, and any simplifications are considered carefully. For example, it may be unnecessary to develop a model of the wider economy for a transport infrastructure investment in which the majority of the network effects will be confined to the transport market. However, such a simplification would be questionable for a programme of investments that are focussed on the creation of new networks, such as the TEN-T programme, where network effects are expected in both the transport market and the wider economy.

3.3 Network effects, total economic impact and economic appraisal

By total economic impact, we mean simply the aggregate change in social welfare (see for example Mackie *et al*, 2001). If prices equal marginal social cost in the transport using sectors of the wider economy, then a full measure of total economic impact can be calculated from an analysis of impacts in the transport market (e.g. changes in travel times, travel demands and travel costs). Consequently, in that case, a good quality transport model with an appropriate transport supply and demand representation will provide a robust measure of total economic impact. This approach underpins transport cost benefit analysis (TCBA).

The implications on total economic impact of a mis-specification of the TCBA can be significant. Van Exel *et al* (2002) cite three major infrastructure projects – the high speed rail link between Amsterdam and Paris, the freight rail link between Rotterdam and Antwerp and the expansion of Rotterdam harbour - where the artificial truncating of the TCBA to national borders excluded between 25% and 60% of the benefits of the projects. For projects at a more local level Beavis (2003) clearly identified the consequences of including or omitting certain interactions when appraising one trunk road improvement in the UK. Beavis found that exclusion of parts of the transport network from the TCBA could artificially inflate the Net Present Value (NPV) of the project by 37%. It is therefore clear from these two examples that exclusion of network effects that occur within the transport market from a TCBA, can either underestimate or overestimate the economic impact of a project. Laird *et al* (2003 see Annex 1) also demonstrate this but at a conceptual level. If the network or link that is excluded from the TCBA is congestible and is complementary to the new transport project, then the TCBA will overestimate the economic impact. If however the new transport infrastructure acts as a substitute for the excluded and congested part of the transport network then the TCBA will underestimate the economic impact.

A ‘correct’ TCBA only provides a precise measure of total economic impact if prices equal marginal social costs. In reality prices may differ from marginal social costs because of, for example, the presence of spatial monopolies in the product markets and/or imperfect labour markets. If the transport investment leads to changes in demand for goods and labour, supplied through imperfect product and labour markets, welfare surpluses (and losses) occur that are additional to those measured in the transport market. In such a situation a complete calculation of total economic impact requires the inclusion of the transport/economy network effects addition to those that occur within the transport market. This calculation has to be undertaken in a manner that avoids double counting - for example by measuring the change in aggregate welfare at the household level in an SCGE model.

Are these transport/economy network effects quantitatively significant? The first thing to note is that depending on market conditions the unaccounted elements of total economic impact when price does not equal marginal social costs may be positive or negative in sign (SACTRA, 1999). In terms of the size of these unaccounted elements relative to those that are included in a TCBA the evidence is mixed. The theoretical work of Venables and Gasiorek (1999) found that if a transport project were able to reduce the cost mark-up on trade from 20% to 10% then the additional benefits compared to a TCBA could be in the region of 30%. Newbery's review of their findings, however, indicates that the additional benefits need to be scaled down by a factor of 10 (Newbery, 1998; SACTRA, 1999). The SACTRA committee's final comments indicate that they found additional benefits in the region of 6 to 12% plausible.

Venables (2004) uses a SCGE model of a conceptual city economy, to demonstrate that including agglomeration effects on productivity in an economic appraisal could give rise to between 85% and 147% additional benefits for commuting journeys compared to a TCBA (for a 20% reduction in commute times). The range in results depends upon the assumption made regarding the impact of taxation. The increase in productivity stems from the consumption externalities associated with thicker labour markets, better input-output linkages and/or knowledge spillovers (i.e. agglomeration economies). Venables' model does not explicitly model the consumption externalities but instead uses an empirically derived relationship between productivity and city size.

There are unfortunately few examples in the literature of applications of SCGE models to real transport infrastructure projects. Oosterhaven and Elhorst (2003) used an SCGE model of the Netherlands that indicated additionality may range from -15% to +85% depending on the type and function of the new transport infrastructure. Crucially, unlike earlier work, their model includes an imperfectly competitive labour market. The additionality they found arises purely from the welfare implications of prices diverging from marginal social costs in the Dutch product and labour markets, with the imperfections in the labour market having the largest welfare implications. Projects which cool an overheated labour market by linking the periphery to the core gain significant additional benefits; whilst projects which contribute to further overheating lose benefits.

With respect to the TEN-T network, the IASON research has indicated that implementation of the TEN-T priority projects may generate between 20% and 30% more economic benefit than would be measured in a normal TCBA (Bröcker *et al*, 2004). The nature of the CGEurope model used in this study means that these benefits primarily reflect the welfare consequences of prices diverging from marginal social costs in the goods (product) markets within the EU.

As mentioned earlier SCGE models are in their infancy and whilst inroads have been made in their development and application to transport situations, there is still substantial scope for further development. The developmental nature of SCGE models is such that no model can yet simultaneously deal with imperfections in goods and labour markets, labour migration, economies of scale in production, agglomeration economies (resulting from consumption externalities) and the treatment of non-working time. This should be borne in mind when interpreting the SCGE model results.

4 CONCLUSION

Network effects in practical transport assessment are sometimes presented as an imprecise but desirable feature of infrastructure projects. This is dangerous: we need to pin the concept down if it is to be usable for policymakers. We define network effects as the second round reverberation effects on unit costs, prices and outputs in related markets . From the perspective of measuring total economic impact it can sometimes be useful to distinguish between transport network effects and those that appear in the wider economy. However, the interesting and unifying point about all network effects is that they arise as a consequence of one or more of the network properties: congestibility, economies of scale, scope or density or consumption externalities.

Whether network effects are captured within models of the transport and economic system depends upon how well these models reflect the network properties identified above. The travel demand response properties of the system, and the evidence base for the set of elasticities and cross-elasticities in particular markets or corridors need to be strengthened particularly for projects that are expected to have significant generation effects. Current models are also weak in the link between demand and supply which determines service quality. For EU wide transport models, necessary for assessing TEN-T investments, the representation of congestion is also a weakness. With few exceptions, interactions between the transport system and the wider economy are not well represented if they are represented at all.

Notwithstanding the practical issues of data, budgets and computing power, a good quality transport model fed by good data should be capable of picking up transport network effects for the vast majority of transport projects. Innovative transport modelling techniques may however be needed for transport projects in which the interaction between public transport supply and the travel demand model are important (e.g. a significant expansion of air and rail networks) or where large transport cost reductions are expected (e.g. connecting different regional or national economies by replacing ferry services with fixed links or providing a new pass through mountains). For network effects that appear in the wider economy, SCGE models linked to a good quality transport model appear promising tools for assessing large projects or programmes. However, much further empirical work, is needed before it can be considered that SCGE models can capture all forms of network effects that appear in the wider economy.

Transport network effects can clearly be significant as shown by the evidence in section 3 of the paper. Therefore, a pre-requisite for a good quality fit for purpose appraisal of a major scheme or policy is a proper consideration of the second round impacts of the scheme on other modes, areas and sectors. Judging when the appraisal focus needs to be broadened to a wider area, perhaps across national boundaries, or from a unimodal to a multimodal focus, or to include the labour or goods markets, is very important.

For projects that have significant impacts on connectivity, transport/economy network effects will also be significant contributors to total economic impact. This is because it is in situations where connectivity is low that prices in the product and labour markets are likely to diverge most from marginal social costs and a step-change in connectivity is also likely to give rise to significant consumption externalities. At this time there is no definitive modelling system that captures all network effects, so the full scale of the economic impact of a project when price does not equal marginal social costs is not yet fully resolved. However, the evidence from the SCGE modelling work to date is that: the key drivers of the system are the labour market, the goods markets and agglomeration economies; the scale of the omitted effects on total economic impact is similar in size, at their most extreme, to a conventional estimate of total economic impact; and very importantly the omitted network effects may lower as well as raise a conventional estimate of total economic impact.

So, network effects are not an infallible magic potion for breathing life into underperforming infrastructure projects. If network effects that appear in the wider economy (e.g. changes in output and employment) are considered a crucial argument in infrastructure decisions, careful economic analysis of their strength and significance on a case by case basis should be made.

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